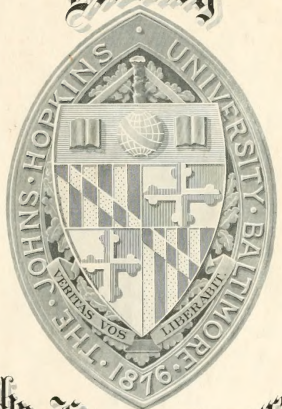
THE EISENHOWER LIBRARY
3 1151 02678 6834

54.389

Library



of the
Johns Hopkins University

On the Electromagnetic Effect of Convection Currents.

Cary T. Hutchinson
Fellow in Physics.

Presented as a Thesis for the degree of "Doctor of Philosophy."
June 1889.

57389

(On the Electromagnetic Effect of Convection Currents)

The first to mention the probable existence of an effect of this kind was Faraday (§), who says:- "If a ball be electrified & suddenly in the middle of a room, & then be moved in any direction, effects will be produced as if a current in the same direction had existed". He was led to this conclusion by reasoning from the lines of force.

Maxwell (*), writing presumably in 1872 or 3, outlines an experiment, similar to the one now used, for the proof of this effect.

The possibility of the

§ Exp. Researches. Vol I Art. 1644

* Elect. & Mag. Vol II. art. 769

magnetic action of Convection Currents
as communicated to Professor Rowland in
1883, & is recorded in a note book
of that date.

In his first experiments
made in Berlin in 1876, Professor
Rowland used a horizontal, hard
rubber disc, coated on both sides
with gold, & rotating between two
horizontal glass Condenser plates.
The glasses were coated on the sides
towards the disc, & each coated
glass surface formed a Condenser
with the coated disc surface near
it. The two coatings of the disc
were charged to the same potential,
while the glasses were earthed.
The Gauss needle of a sensitive
astatic system was placed over
the upper glass plate near the
edge of the disc, so that

5

a radius of the disc - The diameter of the disc was 21cm, & the speed 61 turns per second. The needle system was entirely isolated from direct electrostatic effects by a metallic casing.

On reversing the electrification while the disc was in motion, a deflection of from 5 to 7.5 mm. was obtained, after all precautions had been taken to guard against possible sources of error.

Measurements were made, and the deflections, as calculated & observed, agreed quite well; but it was not possible to attain great accuracy, since the difference of potential was determined from the spark length between knobs, by Thomson's formula. Hence the present experiment, in which a very perfect absolute electromet-

as used for this purpose.

Helmholtz*, in 1870 & later, carried out some experiments bearing indirectly upon this subject. According to the "potential theory" of electrodynamics, which he wished to test, inclosed circuits existed; the end of one of these inclosed circuits should exert an action on a closed magnetic or electric circuit. So the following experiment was made by H. Schiller§, under his direction:-

A closed steel ring was uniformly magnetized, the magnetic axis coinciding with the mean circle of the ring; this was hung in a vertical plane, by a long fine fibre and placed in a closed metal case; a point attached to a Hall machine was placed near

* Wiss. Abh. I p. 778

§ Pogg. Ann. CLIX p. 456

the side of the metal box, in the plane of the ring, and a brush discharge was kept up from this point. If the point acted as a current end, a deflection would be expected, on the potential theory. No motion was observed, although the calculated deflection was 23 scale divisions. The inference is — either that the potential theory is untrue, or that there is no current end in this particular case, i.e. the connection currents completing the circuit have magnetic effects.

Schilling's further work, on hearing directly on Connection Currents, leads him to the conclusion that all circuits are closed, and that displacement currents exist may make no [illegible] —

Dr. Lecher is reported to have repeated Professor Rowland's

experiment, with negative results;
his paper has not been found.

Hertz (*) has discovered a similar action; he rotates a dielectric disc, with no coating on its surfaces, arranged exactly as in Prof Rowland's experiment, & gets a deflection of his needle. He apparently guards against the possibility of this being due to a charge on the disc. A calculation of the force he measures shows it to be about 1/8 of that of the Berlin experiment; his apparatus is not symmetrically arranged, the disc being much closer to the upper condenser plate, the distances from the upper & lower plates being 0.14 & 0.25 cm respectively. He uses a difference of galvanical Correspondence to a

* Sitzb. d. Berl Akad. 19 Jan. 1888

A spark length of 0.3 cm. in air between balls of 2 cm. diameter, i.e. about 33 electrostatic units, equal to the striking potential between plane surfaces at 0.28 cm. The disc is an imperfect conductor, and, altogether, it does not seem clear, in spite of the precautions taken, that this is not due to convection currents.

In the Berlin apparatus the needle was near the edge of the disc; the magnetic effect of a moving charge is assumed to be proportional to the surface density multiplied by the linear velocity; hence the force at the edge of the disc will be much greater than at the centre, but the field will be much less uniform, thus making measurements more difficult.

In the present form of apparatus a uniform field is secured by using two vertical discs rotating about horizontal axes on the same line; the lower element of a sensitive water system is placed midway between the discs, on the line of their axes. Between the needle and each disc is placed a glass plate; each disc is coated with gold on its surface turned towards the needle; each glass plate, on its surface away from the needle - So the coatings of disc & glass plate form a condenser with air as the dielectric - The entire apparatus is symmetrical about the lower needle of the water system -

Each disc is encircled by a gilded hard rubber guard plate

placed in its plane, in order to keep the density of the charge uniform at the edges. The ground plates have screws for adjusting them accurately in the plane of the discs; and the glass plates, in turn, are fitted with the adjusting screws for securing parallelism with the planes of the discs & ground plates. The glass was carefully chosen as having nearly plane. Discs, ground plates, & glass plates, all have radial scratches to prevent [illegible] currents; these scratches do not extend entirely to the center on the discs & glass plates, & one of them is not straight to the outer edge on the ground plates, in order to have an unbroken metallic [illegible].

In the periphery of each disc are set eight brass studs, which

[illegible] radially for about 0.5 cm, then, turning off at a right angle, run parallel to the axis until they come out on the surface of the disc. They there make contact with the gold foil. Metal brushes, set in the guard plates, bear on these studs, and through them the discs are electrified.

Figure 1, drawn to scale of about [illegible], gives a vertical projection of the entire disc apparatus:-
DD-DD are the discs; GG-GG, the guard plates; VV-VV, the condenser plates; RR hard rubber rings fitting on the shoulders AA; XX bearing boxes for the axle; PP supporting standards; EE metal bases sliding in the bed B, & held in position by the screws Z; FF bases carrying the glass plates, & sliding in the same way; SS are the adjusting screws for

the speed plates, & tt the same for the glass plates; dd are cutters for Dutchmen the oil from the bearings; CC, C'C' are speed counters, CC gear with the axle, & C'C' with CC in the manner known; each counter has 200 teeth - Once in every revolution of C'C' the levers VV are lifted & then dropped & time is taken when the levers drop; this gives a speed reading every 40000 revolutions.

The actuator system is enclosed in the brass tube I enclosed in the larger cylindrical box in which the mirror & upper needle are placed. The is closed by the cone a across the opening of which a fine grating is strung, the mirror is shown at M, the upper needle at N', the lenses at R. The needle system is hung by a fine

Suspension about 30 cm. in length, protected by a glass tube. The needle system is made by fitting two small parallelepipeds of wood on an aluminium wire, at its ends; on the two vertical sides of each wooden block are cemented small scraps of watch-spring, tempered glues and strongly magnetised. The needles thus made are about 2×2×10 mm.

The mirror is read by a telescope, with scale, about 200 cm. away. The plane of the mirror is set at an angle of 45° with the direction for the sake of convenience. The entire arrangement is supported by the board OO, attached to a wood bracket.

Two Canchalini magnets are used, with their poles turned in opposite directions; by means of the up & down motion of either magnet

any change in the sensitiveness can be made, & by the motion in azimuth, the zero point is controlled. The advantage of this use lies in the extremely delicate means it affords of changing the sensitiveness, much more delicate than when a single magnet is used.

The bed plate B is screwed to one of a table at the other end of which a counter shaft of brass is placed; (Figure 2) this Countershaft is run by an electric motor placed in the next room, the belt passing through the open doorway. The motor is 12 metres from the needle.

Although the discs & Countershaft were carefully balanced when first started, the table braced & weighted by a heavy stone slab, yet

At the high speed used, 12 revs. per sec, the shaking of the entire apparatus was considerable; the needle was so unsteady that it could not be read. There was seen to be no vibration of the telescope itself, & not of the needle. To prevent this, each leg of the table on which the telescope rested was set in a box about 30 cm deep filled with sawdust, & a heavy stone slab was put on the table. This entirely stopped the vibrations; the swing of the needle was now as regular when the apparatus was revolving as when it was at rest.

The two hard rubber rings mentioned above have grooves cut in their peripheries; in these grooves coils are wound which serve as a galvanometer for determining the speed constant. The [illegible]

use they are held in the position shown in the figure; but when it is desired to determine the needle constant they are slipped on the shoulders A A fitted up into contact with the back of the discs. Each ring is wound with two turns; this arrangement will be referred to as the "Disc galvanometer".

If a known current be sent through the disc galvanometer and the geometrical constant be known from measurements of the distances, the deflection will give the part of the constant depending on the field & the moment of the needle. The current is measured by a fine galvanometer placed in another part of the room. To determine "H" at the fine galvanometer, a [illegible]

the sine galvanometer, and the needle of the latter used as the needle of the tangent galvanometer then made.

Using this tangent galvanometer in connection with a Weber electrodynamometer, "k" is determined.

The discs were charged by means of a Holtz machine connected to a battery of six gallon Leyden jars; in circuit also there is a reversing key, and an idiostatic gauge for keeping the charge constant.

The potential was measured by a large absolute electrometer. In this instrument, the movable plate is at one end of a balance arm, from the other end of which hangs, on knife edges, a balance pan; this plate is surrounded by a guard ring. The larger plate is fixed, by an

insulating rod, to a metal plate which slides up & down through guides. The distances are read off from a scale on the metal stem; the zero reading is determined by inserting a piece of plane parallel glass whose thickness has been measured. The lower plate & guard ring have a diameter of 35 cm., the suspended disc, 10 cm..

The routine of the observations was as follows:- A determination of $\frac{H}{\beta}$ & the needle constant (β) was first made. The idiostatic gauge was then set at a certain point, & readings of the difference of potential corresponding to this position were taken on the Absolute Electrometer. The discs were now started, electrified & a series of three elongations of the

taken; the electrification reversed, & three more elongations taken, viz. About every five minutes Speed readings had to be noted, and at each reversal it was necessary to replenish the charge slightly. (In this way a "series" of readings consisting of from 20 to 30 reversals was taken; after the series, electrometer readings were again made; then the conditions were changed in some way, as changing the distance of the discs from the needle, or the distance of the glass plates from the needle, or the electrification, or the direction of rotation, and another series begun -

The calculation of the deflection is based on the assumption that the magnetic effect of the rotating charge is proportional

to the quantity of electricity passing any point per second, just as in a voltaic current. Below are the formulae used; all quantities will be given in C.G.S. units, unless otherwise mentioned. The letters used have the following meanings:—

x = distance from center of disc to lower needle

r = " " " " " " upper "

c = radius of discs =

l = distance between the needles =

a = radius of winding of disc galv. =

b = distance center disc. galv. & lower needle

ρ = " " " " " upper "

N = no. revolutions per second.

σ = surface density of electrification, in electrostatic units.

$V = \frac{\text{Electromagnetic unit of Quantity}}{\text{Electrostatic " " "}} = 3 \times 10^{10}$

α = angle of torsion of electrodynamometer

φ = " " deflection of the same galvanometer

δ = Angle of deflection of the large mirror galv.
Δ = Change of zero point on electrometer by moving the discs = Half the change on reversing.
s = Scale reading for disc galv.
w = Weight in pan of electrometer = .503
D = Reading of electrometer scale.
l = distance of glass plates + discs, i.e. the condenser distance.

Force, due to a circular current of radius c, in the direction of the axis, at a point on the axis distant x from the plane of the current

$$= 2\pi I \frac{c^2}{(c^2+x^2)^{3/2}}$$

Strength of connecting current

$= 2\pi c\, dc \frac{N\sigma}{v}$ in electromagnetic measure.

$\therefore$ Total force due to disc of radius c

$$= 4\pi^2 \frac{N\sigma}{v} \int_0^c \frac{c^3 dc}{(c^2+x^2)^{3/2}}$$

$$= 4\pi^2 \frac{N\sigma}{V} \left\{ \frac{c^2 + 2x^2}{(c^2+x^2)^{1/2}} - 2x \right\}$$

$$= 4\pi^2 \frac{N\sigma}{V} \times A.$$

And for two discs acting in the same direction, the total force,

$$X = 8\pi^2 \frac{N\sigma}{V} A.$$

This gives the force on the lower needle.

Correction for the upper needle;—

Potential at any point due to a circular current I,

$$V' = \int I \, d\omega ,$$

ω = solid angle subtended by the circle at that point,

$$= 2\pi \left\{ \tfrac{1}{2} P_1\left(\frac{c}{r}\right)^2 - \frac{1.3}{2.4} P_3 \left(\frac{c}{r}\right)^4 \cdots - (-)^i \frac{1.3.(2i-1)}{2.4\ldots 2i} P_{2i-1}\left(\frac{c}{r}\right)^{2i} \right\}$$

$(i = 1.2.3.\ldots)$

$\therefore$

$$V' = 2\pi I \sum_i \left\{ -(-)^i \frac{1.3\ldots(2i-1)}{2.4\ldots 2i} P_{2i-1}\left(\frac{c}{r}\right)^{2i} \right\}$$

Substituting the value of I, have for the potential due to the disc

$$V = 2\pi \sum_i \int_0^c 2\pi c \frac{N\sigma}{V} \left\{ -(-)^i \frac{1.3\ldots(2i-1)}{2.4\ldots 2i} P_{2i-1}\left(\frac{c}{r}\right)^{2i} \right\}$$

$$= 4\pi^2 \frac{N\sigma}{V} c^2 \sum_i \left\{ -(-)^i \frac{1.3\ldots 2i}{2.4\ldots 2i(2i+2)} \frac{1}{2i+1} P_{2i-1}\left(\frac{c}{r}\right)^{2i} \right\}$$

But $$P_i' = (-)^i \frac{i^{i+1}}{1.2\ldots i} \frac{\partial^i}{\partial x^i}\left(\frac{1}{r}\right)$$

$$\frac{\partial}{\partial x} P_i = \frac{i+1}{r}\left\{ \mu P_i - P_{i+1} \right\} \quad \mu = \frac{x}{r}$$

$\therefore$ the force along the axis

$$= -\frac{\partial V}{\partial x}$$

$$= 4\pi^2 \frac{N\sigma}{V} c^2 \sum_i \left[\left\{ (-)^i \frac{1.3\ldots(2i-1)}{2.4\ldots 2i(2i+2)} \right\} - \frac{2i c^{2i}}{r^{2i+1}} \mu P_{2i-1} \right.$$

$$\left. + \left(\frac{c}{r}\right)^{2i} \frac{2i}{r}\left(\mu P_{2i-1} - P_{2i} \right) \right\} \Bigg]$$

$$= 4\pi^2 \frac{N\sigma}{V} c^2 \sum_i \left\{ (-)^{i+1} \frac{1.3\ldots 2i-1}{2.4\ldots 2i+2} \frac{2i}{r} \left(\frac{c}{r}\right)^{2i} P_{2i} \right\}$$

used for two discs, deflecting upon two arms,

$$X_1 = 8\pi^2 \frac{N_1}{v} \frac{c^2}{r} \left\{ \frac{1}{4} P_2 \left(\frac{c}{r}\right)^2 - \frac{4.3}{2.6} P_4 \left(\frac{c}{r}\right)^4 \cdots \right\}$$

where the sign of the entire expression has been changed, since the scales of the upper & lower arms are in opposite. Or

$$X_1 = 8\pi^2 \frac{N_1}{v} . B$$

Needle constant.

For the disc galvanometer undergo the forces are calculated in the same way.

Force on the lower needle

$$= 2\pi I \frac{a^2}{(a^2+b^2)^{3/2}} = 2\pi I . b.$$

used for the four turns, total force

$$X' = 8\pi I . b$$

Upper needle. Same as for the last, omitting the integration, we must multiply the general term of β by $\frac{2(i+1)}{a^2}$ & replace $2\pi\frac{N\sigma}{v}$ by I

Then have

$$2\pi I \sum_i \left\{ (-1)^{i+1} \frac{1.3 \ldots (2i-1)}{2.4 \ldots 2i} \frac{2i}{\rho} \left(\frac{a}{\rho}\right)^{2i} P_{2i} \right\}$$

"a" replacing "c", "b", "h" —

The total force,

$$X' = 8\pi I \frac{1}{\rho} \left\{ P_2 \left(\frac{a}{\rho}\right)^2 - \frac{3}{2} P_4 \left(\frac{a}{\rho}\right)^4 \ldots \right\}$$

or

$$X' = 8\pi I . \Delta .$$

Forces acting on the astatic system —

Let M = magnetic moment of lower needle.
M' = " " " upper "

Then
Couple on lower needle due to the fields = $N M \sin \vartheta$
" " upper " " " " = $-N' M' \sin \vartheta$

Total couple $= (N m - N' m') \sin\vartheta -$

Due to current in disc & alternometer,

Couple on lower needle $= m X' \cos\vartheta$

" " upper " $= m' X_1' \cos\vartheta$

Total couple $= \{ m X' + m' X_1' \} \cos\vartheta$

$= 8\pi^2 I \{ m b + m' D \} \cos\vartheta$

$\therefore$ in equilibrium

$$8\pi^2 I \{ m b + m' D \} \cos\vartheta = \{ N m - N' m' \} \sin\vartheta$$

or

$$I = \frac{(N m - N' m')}{8\pi (b + D) m \left\{ 1 + \frac{D}{b} \left(\frac{m'}{m} - 1 \right) \right\}} \tan\vartheta$$

But $\frac{D}{b} = 0.03$ nearly, & $\frac{m'}{m} = 1$ nearly

$\therefore$

$$I = \frac{(N m - N' m')}{8\pi m (b + D)} \tan\vartheta.$$

or $$\frac{(N m - N' m')}{m} = \frac{8\pi (b + D)}{\tan\vartheta} I = \beta \text{ (say)}$$

Similarly for discs

$$8\pi^2 \frac{N a}{v} \{ A + B \} = \frac{N m - N' m'}{m} \tan\Delta'$$

$= \beta \tan \Delta'$.

$\tan \Delta' = \Delta \div$ scale distance; $\tan \vartheta = \vartheta \div$ scale distance. Since the quantities enter as $\frac{\tan \Delta'}{\tan \vartheta}$, they may be replaced by $\frac{\Delta}{\vartheta}$;

$$\therefore \quad V = 8\pi^2 \frac{N\sigma}{v} \frac{A+\beta}{3.\Delta}$$

Numerical constants —

Sine galvanometer:

$$I = \frac{H}{T} \sin\varphi \; ; \quad T = 1831.2$$

$$\therefore$$

$$I = 10^{-4} 5.46\, H \sin\varphi$$

$$\beta = 10^{-4} 5.46\, H \frac{8\pi(6+\Delta)}{\delta} 2 \sin\varphi -$$

Electrodynamometer.

$$i = q \frac{\sqrt{K}}{T} \sqrt{\sin\alpha}$$

q = constant of [illegible] $= 10^{-3} 6.454$

K = Moment of Inertia = $10^7 8.266$

T = time of one swing (half period) = 2.441

$\therefore$

$$i = 10^{-2} 7.59 \sqrt{\sin \alpha}$$

Tangent galvanometer.

$$i = \frac{N}{G} \tan \delta = \frac{N \cdot b}{2\pi n} \tan \delta$$

n = no. turns = 10

b = radius of turns = 49.98

$\therefore$

$$i = 10^{-1} 7.95 N \tan \delta;$$

substituting the value of i

$$N = 10^{-2} 9.55 \frac{\sqrt{\sin \alpha}}{D}$$

Surface density.

$$\sigma = \frac{V}{4\pi e}$$

$$V = \Delta \sqrt{\frac{8\pi g w}{A}}$$

A = corrected area of disc rounded plate.
$= \frac{1}{2}\pi\{R_1^2 + R_2^2 + \ldots\} = \frac{1}{2}\pi\{51.01\}$

$\therefore$

$$V = 17.56\, S\sqrt{w}$$
$$\sigma = 1.397\, \frac{S}{\ell}\sqrt{w}$$

As soon as the attempt was made to electrify the apparatus, difficulties of insulation were met with; the charged system was quite extensive & the opportunity for leakage was great; in addition the weather here has been quite damp. Most of the insulation trouble here has been due to the glass used in the apparatus; in no case where it was used has the insulation proved satisfactory, not even when the air was dry. Even the stand with glass legs, on

which the condenser battery was placed was found to furnish an excellent earth connection. Paraffine, Colodion, Shellac &c. stopped this. The reversing key had three glass rods in it all of which were found to leak; various apparent specimens of glass, some bought particularly as insulating glass, were all found to allow great leakage; Hard rubber was finally substituted for the glass, & after that the key insulated very well even in damp weather.

My aim in changing the glass plates, the discs being earthed, it seemed almost as if there were a direct earth connection, so rapid was the fall of the charge. This was not regarded at the time, as the

plates were always kept earthed. But, later, when it became necessary to charge the plates, the insulation had to be made good.

Investigation showed that loss was caused by leakage directly through the substance of the glass to the brass back pieces. Hard rubber pieces were substituted and this trouble was entirely done away with.

There was at first a deflection on reversing the electrification while the discs were at rest. This was of course due to direct electrostatic action, but it for some time clung just where the point of weakness in the electrostatic screen lay. It was found to be finally connected with the imperfect

a, the glass tube and the brass collars, which had been lacquered, after this was corrected there was never again any deflection on reversing, while the discs were at rest, although the precaution was taken of testing every day or so.

The currents induced in the axle by its rotation in the earth's field caused no inconvenience; if the discs are rotated in the same direction, then effects added, while that of the axles is in opposite directions. Even when the discs were rotated oppositely, the deflection due to the axles was only three or four centimeters & remained perfectly constant.

On running the discs, unelectrified, without the glass plates between them & the needle, a deflection of 4 or 5 centimetres was noticed: this was a perfectly steady deflection & could easily be shown to be due to the presence of the plates, as it ceased entirely when they were replaced in position. This was very troublesome for a time, as readily as the presence of a brass plate in place of the glass was found to diminish the deflection, but did not bring the needle entirely back to zero as the glasses did. On looking at the figure it will be seen that there is a brass plug closing the bottom of the tube in which the

needle is placed. The rapid rotation of the discs caused a very appreciable exhaustion at their centers, and a steady stream of air was sucked down the tube, through the open mouth piece above. Air currents were not at first suspected, as the deflection was so very steady. The brass plate used was smaller than the glass, and hence did not completely shield the the tube—

After the brass discs had been taken out and hard rubber ones substituted, it was found that with one direction of rotation the needle was very unsteady; it would run up the scale for several centimeters, stop suddenly, then

&c; evidently a forced exhalation.

This was traced to air currents also. Now, the air blew into the open conical mouth piece. The apparatus had been run for some months with this open & not the slightest irregularity had been seen; but, the hard rubber pieces were very much larger than the brass ones which they replaced; they filled up the lower space to a greater extent, & deflected the air upwards more than before. During the unsteadiness. With the opposite rotation, the air was thrown down instead of up, & consequently did not affect the needle.

The work was begun in October 1888, but the first

Systematic observations were not made until January 1889; these were all made with the discs charged & the plates earthed.

The deflection on reversal was got without difficulty, and it was in the direction to be expected, that is,— with positive electrification, the effect was equivalent to a current in the direction of motion of the disc. A number of series were taken in the next two months, & although they agreed well enough among themselves, they did not follow the law assumed. The deviation can best be explained in this way:—

The equations show that for a fixed position of the disk,

$\Delta \propto \frac{N}{\beta} \propto \frac{D}{e}\frac{N}{\beta}$. If then,
$N \div \beta$ being kept constant, the
Cavendish plates are moved up
to or away from the discs,
step by step, thus varying "e", and
"D" be changed at the same time
so as to keep $D/e \propto \sigma$ a constant,
the deflections should be constant.
Such was not
found to be the case, the deflections
as nearly as could be judged, were
directly proportional to "e"
instead of being constant; that
is - with greater difference of
potential the deflections were
greater even though the surface
density were constant.
Finally this was found to be
due to a charge on the back
surface of the gold coating.
The edge of the disc would

nearly up to the surface of the disc, and taken with all the ironwork, must form a condenser of a certain capacity with the inner surface of the foil.

This made a change necessary in the method of working; the disc had to be earthed and the plates charged. This was done, but now the deflections were always found to be greater with positive rotation (Zenith, North, Nadir, South,) than with negative. It was thought possible that the brushes might have something to do with this, so they were taken off. Earth connection with the coating of the disc was made by dipping through to the

surface of the disc in the line of the axle, and setting in a screw which came flush with the surface of the disc and also made contact with the end of the axle. This, however, made no difference, the deflections for positive rotation continued always to be greater.

Table I gives the results of a number of observations, all taken with the discs earthed by means of the axle, & the plates charged

No. of Series	Rotation	X	ℓ	N	δ	1/3 $10^5 x$	2Δ mm.	V 10^{10}
1	+	2.54	1.32	122	1.16	1.50	5.3	2.47
2	+	2.57	"	125	1.20	3.11	9.0	3.38
3	+	"	"	129	1.23	2.15	6.9	3.00
4	−	"	"	129	"	"	5.6	3.68
5	+	"	1.21	127	1.21	2.25	5.6	3.74
6	−	"	"	133	"	"	5.7	3.74
7	+	"	"	130	1.47	"	8.4	3.10
8	−	"	"	133	"	"	7.3	3.64
9	+	"	1.24	121	1.32	2.22	9.4	2.26
10	−	"	"	130	"	"	7.2	3.16
11	+	"	"	125	1.26	2.17	7.6	2.70
12	−	"	"	126	"	"	5.7	3.64
13	+	2.85	1.50	125	1.19	2.23	6.5	2.82
14	−	"	"	129	"	"	5.0	3.78
15	−	"	"	125	1.11	2.19	5.85	2.82
16	+	"	1.43	127	1.08	2.35	7.3	2.46
17	−	"	"	128	"	"	5.4	3.32
18	−	"	"	129	"	"	5.3	3.42
19	+	3.22	1.80	123	1.13	2.44	5.1	3.30
20	−	"	"	124	"	"	4.9	3.48

Average V = 3.19×10^{10}

The meaning of most of the letters has been given 1/β is directly proportional to the needle sensitiveness.

Each series is the average of from twelve to sixteen readings; it was found to be of no particular advantage to take more; the average of twelve was substantially the same as the average of twenty five, and as it took from thirty to forty five minutes to get twelve deflections, it seemed that greater errors would be introduced by the extension of the time than would be eliminated by having a larger number of observations.

The sudden changes in the values of 1/β are due to changes purposely

made in the magnets — The last column gives the value of v; but this work is not intended as a determination of v; the calculation is put in this form merely to show to what degree of approximation the effect follows the law assumed

The deflections are about the same as those obtained in the Berlin experiment, — 5 to 8 mm. on reversing. The force measured then was $1/50000$ N; now, it is $1/125000$ N. The sensitiveness of the needle in the two cases was almost the same; in the former experiment a force of 3×10^{-7} deflected the needle 1' of arc; the corresponding force now is 2.7×10^{-7} — slightly more sensitive. The needle

distances were 110 & 200 cm. respectively. So this arrangement gives about the same scale deflection at these distances with a force 4/10 as great. The agreement between the two is seen to be quite good.

Most of the observations given above were taken in pairs: i.e. with first one direction of rotation followed immediately by the other, everything else remaining just the same. Nos 1, 2 & 15 are exceptions. The table shows that in every case except one, the deflection for negative rotation is appreciably smaller than for positive.

This difference is too great to be accidental, as the following table

the individual deflections will be:

Table III

	# 13		# 14
(+)	6.7 mm.	(−)	5.1
	5.1		4.9
	6.6		3.9
	7.6		5.2
	8.0		5.0
	5.8		5.2
	6.3		4.9
	8.0		5.0
	8.0		5.0
	4.3		4.4
	5.9		6.6
	6.0		5.0
Ave. =	6.5	Ave. =	5.0

There is but one deflection in #13 as small as the average of #14, & but one in #14 as

large as the mean of ± 13 - This is a fair example of the way the deflections run. As a further illustration, take Nos. 1-7 & 8, these two are identical in arrangement, but the direction of rotation is in the one case got by crossing the belts from the countershaft to the disc and leaving the main belt straight; in the other, the main belt is crossed while the auxiliary belts are straight. The deflections are the same as they should be. This shows that difference can not be due to any effect of the countershaft.

The cause of this is not yet been discovered. The work is to be continued with this and with new apparatus, made lately at the Berlin

experiment, but with the disc much larger - 30cm. in diameter, at least double the size obtained will be used; this ought to give a deflection of 1.5 to 1.7 cm. on reversal.

The values of "V" do not agree as well as might be looked for; but when, in addition to the numerous difficulties already mentioned, the smallness of the deflection is considered, and the possibility of the needle being affected by currents or magnets in other parts of the laboratory, so far away as not to be guarded against, and which might well be changed between the times of taking the observations themselves & of taking the needle

Constant, and finally, and
Lastly, that a disturbing
Cause of some kind is that
undoubtedly present, the
agreement is seen to be as
good as could be expected.

Autobiography of Isaac A—

Autobiographical

I, Cary Talcott Hutchinson, was born in St Louis Missouri, March 4 1866. I first was sent to a private school in St Louis, but only for a year. Then I entered the public schools & remained there until I got as far along as the High School. At this time, I entered the Smith Academy, an academy kept up in connection with the Washington University; After three years at the Academy, I entered the Washington University as a Freshman at the age of 16. I was graduated by the W. U. in June 1886 with the degree of A.B. Magna Cum Laude.

The College courses at the W. U. led to the two

degrees of A.B. & Ph.B. The first was the Classical course, the second, the same with Physics substituted for Greek. I took the latter. In each course there were two or three subjects which were absolutely required, & a choice was given of three or four electives out of a dozen or more. In the Ph. B. course particular stress was laid upon English history, language, & literature, and upon French & German history language, & literature next. In addition to the college, there is a fully equipped school at the U. of M., the courses running parallel as far as possible, & the students being together in much of the work. I wished the engineering work in addition to my

& by a judicious intermingling of required & elective, I was enabled to take the two full courses, with about half as much work again as either would have been. By this, in addition to the general engineering training I had an extensive course in Manual training.

At my graduation I elected to receive both engineering & Ph. B. degrees; but I was told that although I might have either degree, yet I had not done the work for both, & could not get both. I chose the Ph. B.

In my Junior & Senior years, I had devoted myself particularly to Physics, mainly electricity — I studied typ —

with the study of electricity as a chance of the Massachusetts Institute of Technology was offered. I came here in one year, but found that it would take me two to do the work of the electrical course, so I stayed, & last June received my Certificate in the electrical course. Being appointed a Fellow, I remained another year —